Making Green Building Units By Using Some Wastes of Ceramic Industry

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Abstract:
The ceramic tiles industry produces a lot of wastes such as ceramic sludge, broken under quality tiles and the ceramic dust. The accumulated wastes comprise a great pollution problem on the surrounded environment. The ceramic properties of Egyptian clays show that they are highly plastic and very sensitive upon drying. Accordingly, they are continuously in need to some additives for adjusting such properties.

The environmental impact of this work is producing a green building unit has a zero waste energy. The recycling of ceramic solid waste industry in building operations contributes with minimizing the energy consumption and the cost of building to achieve building sustainability. In this work each of 15, 25 and 50% ceramic sludge solid waste were mixed with a chosen clayey raw material for making green building bricks.

The mix contains 15% sludge and 85% clay shows a lower plasticity coefficient and an insensitive behaviour upon drying in addition to suitable physico-mechanical properties for the fired clay articles. This suggested mix was applied within a common brick fabric in Egypt for studying the possibility of its industrial application.

1. INTRODUCTION

In the last few years, many researchers were interested in studying the problem of industrial wastes. Building material industries continuously produce various types of wastes. Accumulation of such wastes could be considered as one of the main sources for the environmental pollution. Ceramic tiles industry produces different kinds of wastes, such as dust collected by the filters of chimneys; broken tiles which may be refused through the quality control process and finally, the sludge which produced during recycling of water through special pressed water filters. Sludge is a type of ceramic tiles industry wastes which represents a terrible problem inside the factory due to its daily accumulation and its disability for recycling in the ceramic tiles industry. Also, this sludge causes a serious problem outside the factory; since throwing it away certainly leads to an environmental pollution. This work aims to study the possible utilization of ceramic waste sludge in the clay building bricks industry. The main target is producing green building units which will share in saving the cost and energy of buildings. Various Egyptian clays, were previously investigated by many authors. For instance, Abd El-Ghafour[1] studied textural, chemical and mineralogical composition of Kom Osheem clays(El-Fayoum Governorate, Egypt). Utilization of ceramic sludge in building clay bricks could be investigated by mixing the clayey raw material with various percentages of sludge. These mixes were moulded, dried, and fired at ranges of temperatures suitable for building bricks. The fired articles would be evaluated through their physical and mechanical properties. Finally, the most suitable mix could be utilized on an industrial scale within one of widespread Egyptian brick fabrics.

2. MATERIALS AND METHODS

The materials used in this work were clays from Kom Osheem area (El-Fayoum Governorate, Egypt) and a ceramic sludge as a waste product from a ceramic factory lies near to the studied clayey material.

The mineralogical composition of the studied raw materials was examined using a Philips PW 1050/70 X-ray diffractometer. The powder X-ray diffraction method was used for the identification of non clay minerals. The oriented aggregates of the <2mµ fraction method was used for the identification of clay minerals through methods of untreating, glycerol solvating and heating at 550°C for 2 hrs. The identification of clay and non-clay minerals was based on the mineral powder diffraction file data book[2]. The semi-quantitative estimation of the separated clay minerals was calculated according to the method of Johns et al[3] Philips PW-1400 X-ray florescence spectrometer and traditional chemical analysis method were applied for studying the chemical composition of the clay samples.

To evaluate the suitability of the clay/ceramic sludge mixes for making building bricks, each of clay and ceramic sludge samples were dried, ground and sieved through 1-mm sieve. Four clay/ceramic sludge mixes with 0, 15, 25 & 50% ceramic sludge additives were prepared. The ceramic properties in terms of plasticity as well as drying and firing behaviour were determined. The plasticity measurements were carried out adopting the method of Pfefferkorn4; based on deformation caused by the action of a piston on clay cylinders of different water contents. Water content corresponding to a compressibility = 3.3 is considered as the plasticity coefficient (PC) i.e. water of plasticity. On the other hand, the drying behaviour was calculated according to ASTM5. The obtained data were used for drawing Bigote's curves6 from which the drying sensitivity coefficients (D.S.C.) were calculated for each mix. Physical and mechanical properties were studied after firing the dried articles at 800, 850 and 900oC with 1 oC/min interval of firing and 2hrs soaking time.

3. Results and Discussion

The studied clays contain clay > silt > sand particles. They had a grain size distribution ranged from silty clay, clayey mud to silty mud according to the classification of Picard[7]. On the other side, the ceramic sludge has a random size distribution with a nearly trimodal classes, (Fig. 1).

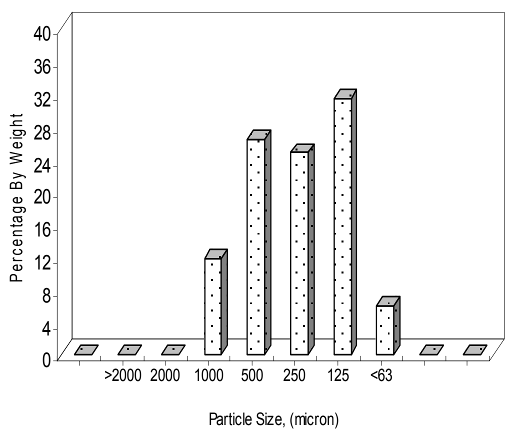

Figure 1. Histogram shows the particle size distribution of the studied Waste ceramic sludge.

The clay powder sample (non-clay fraction) is composed of quartz, feldspar, gypsum and calcite. On the other side the clay fraction is composed of montmorillonite, kaolinite, montmorillonite – illite and illite clay minerals in a descending order of abundance, (Abd El – Ghafour[1]). The mineralogical composition of the dried powder ceramic sludge is composed mainly of quartz and albite in addition to kaolinite and illite, (Fig. 2).

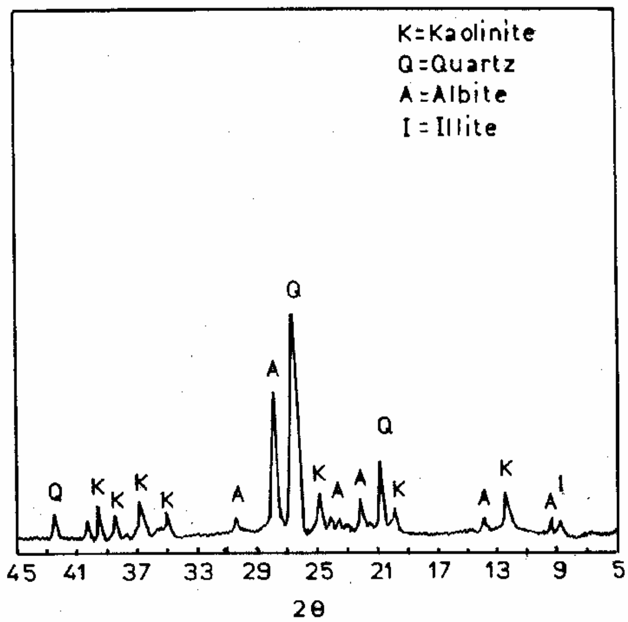

Figure 2. X-ray diffraction pattern of the studied ceramic waste sludge.

The data of chemical analysis (Table 1) indicates that the studied clays contain high SiO_2 (54.51%) and low Al_2O_3 content (19.64%). These values could be attributed to the presence of clay minerals, feldspars and quartz. It's obviously that, the chemical composition of such clay sample is in agreement with its mineralogical composition.

The chemical composition of the studied ceramic sludge reveals its enrichment with SiO_2 (61.43%), CaO (4.78%), and Na_2O (2.17%). The percentage of Al_2O_3 in the sludge is nearly similar to that in the clay sample . Generally, the more or less close chemical relationship between the studied clay and ceramic sludge has encouraged designing different mixes between them.

Table 1. Average chemical analysis data of the clay and ceramic waste sludge materials.

Oxides Content	Clayey Material	Ceramic Sludge
SiO_2	54.51	61.43
Al_2O_3	19.64	19.13
Fe_2O_3	4.18	3.29
TiO_2	1.33	0.96
CaO	5.78	4.78
MgO	1.28	1.22
Na_2O	1.14	2.17
K_2O	1.40	1.04
SO_3	0.60	0.14
L.O.I.	10.10	5.76
Total	100.00	99.92
Soluble Salts		
Cl^-	0.71	0.05
SO_4^{--}	0.24	1.81
Na^+	0.66	0.97
K^+	0.14	0.35

The type of clay minerals and its particle size distribution are the principal factors affecting the plasticity of clays, (Platen & winkler)[8]. According to Pffeferkorn's technique[4], Figure, (3) shows that, utilized clay is characterized by a high plasticity coefficient (P.C = 32.5). This can be attributed to the high content of montmorillonitic clay minerals as well as the high clay fraction. These results coincide with the mineralogical and textural composition of such clay. It was observed that, as the ceramic sludge additives are increased the PC is gradually decreased to 28.7 with 50% ceramic sludge. It's also observed that, for a mixture of 85% clay, and 15% ceramic sludge the P.C decreases to (31.7). This limited decrease in PC will not affect greatly the plastic behaviour of the mix but may keep good ceramic properties, for the end product. The presence of more plastic clays leads to good ceramic properties (Searle & Grimshaw[9] and Abdel Ghafour[10]).

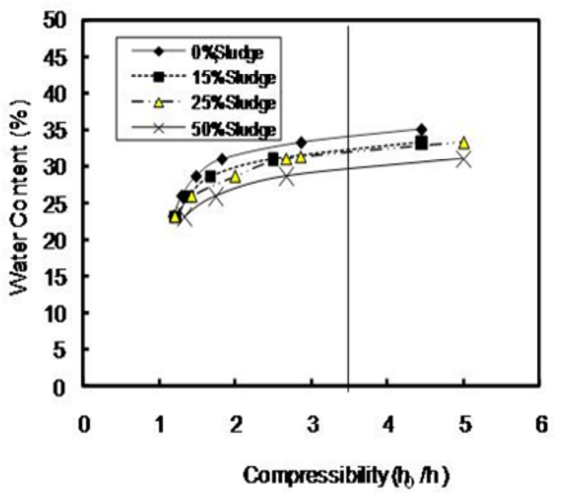

Figure 3. Plasticity curves of the studied clays with various percentages of ceramic industry waste sludge.

Plastic pastes of the clay sample as well as their mixtures with ceramic sludge (0, 15, 25 & 50%), were hand molded into cubes of 5 cm side length. The percentage of the linear shrinkage during drying process was determined and plotted as a function of the percentage of water content (Bigot's curves, Fig.4). The drying sensitivity coefficient (D.S.C.) was calculated from these curves. The D.S.C. of the studied clay (2.18) indicates that such clay is sensitive upon drying (ASTM[5]) due to its high clay fraction and its montmorillonitic clay minerals. Generally, it should be noted that drying shrinkage of such low grade clay is also attributed to the amounts and the particle size of clay minerals. At the same time the amount of water lost during drying is proportional to, but not equal to, the amount of shrinkage. The D.S.C. of clay / ceramic sludge mixtures decreases in the order 1.00 > 0.93 > 0.87 against 15, 25 & 50% ceramic sludge additives, respectively.

This means that addition of 15-50% of ceramic sludge leads to decrease the D.S.C from very sensitive (2.18) to insensitive (0.87-1.00) mixes during the drying process. Such values declare insensitive and safe drying behaviour without effect on the plastic and workable nature of the sludge-bearing mixes.

The dried green articles were fired in an electric furnace at temperatures between 800^o-900^{o}C. The data of physico-mechanical properties are listed in Table 2, and their graphical relationships are represented in Figures (5&6). Rising firing temperature increases firing shrinkage percentages and bulk density values of the fired clay articles. Addition of up to 50% ceramic sludge gradually decreases bulk density with increasing linear shrinkage at all firing temperatures. This means that the more addition of ceramic sludge the less firing shrinkage will be obtained. It should be recorded that, the amounts of silica and free quartz included or added to the clayey raw material with respect to the applied firing temperature are responsible to a great extent for the amount and type of firing shrinkage or expansion,(Abd El-Ghafour, 1995[10]). In this work it's noticed that, addition of 50% ceramic sludge partly fixed the ascending trend of firing shrinkage especially by firing at higher temperatures (850 ^{o}-900^{o}C).

The water absorption values also decreases with increasing firing temperature. Generally, the increase of firing temperature decreases the volume of articles and accordingly decreases the pore spaces. The decrease of water absorption percentages and the increase of bulk density values by rising firing temperature indicate an increase in the glassy phase which fills some of the open pores of the fired clay articles due to the progressive vitrification in the clay body. The general decrease in water absorption percentage with increasing the firing temperature indicates an increase in the glassy phases that fill some of the open pores of the fired articles (El-Mahallawy[11]).

Generally, the values of water absorption given by the fired articles could be considered as a direct reflection to the firing shrinkage and bulk density values.

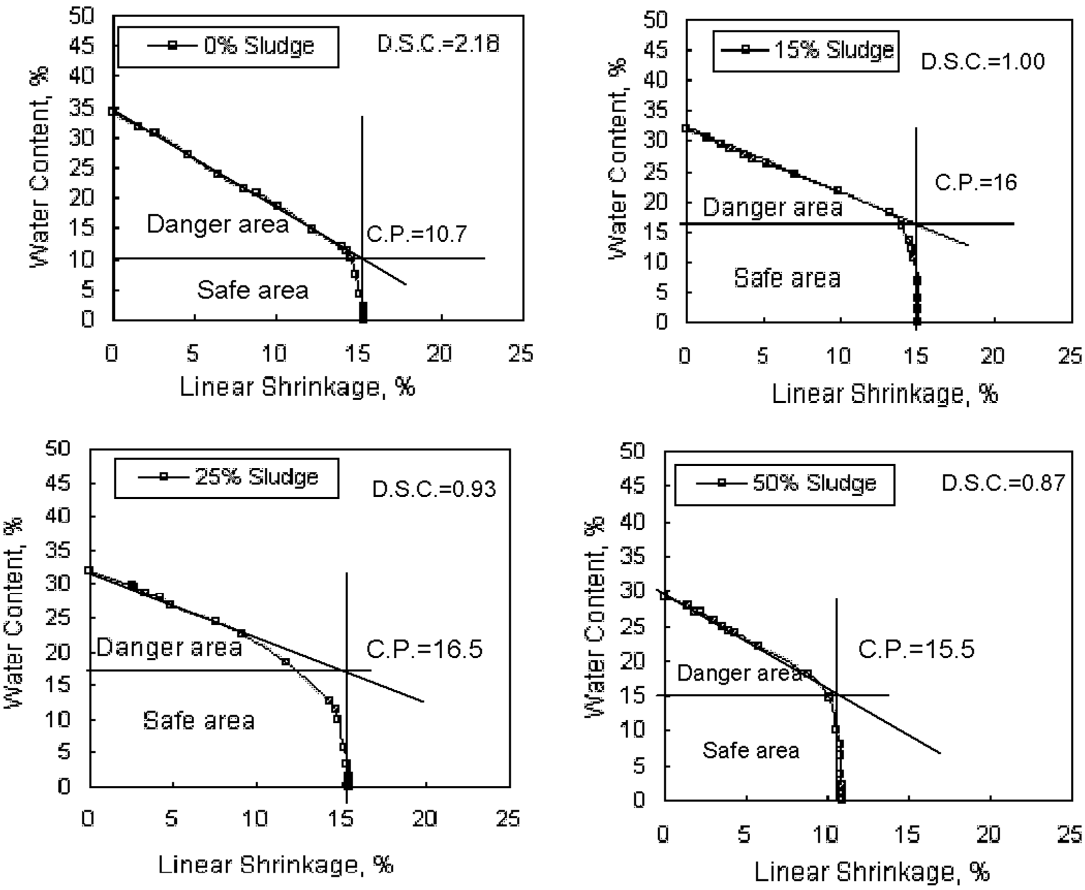

Figure 4. Bigot's curves of the studied dried clay articles.

It should be recorded that, the high content of $CaCO_3$ in the clayey material or in the added waste gives the fired articles more open pores during the release of CO_2 gas through the firing process. This behaviour normally increases the porosity and consequently the water absorption values. By increase the firing temperatures, the porosity and water absorption decrease due to filling of some pores by the formation of the glassy phase (Khalil and Kabesh[12]& Khalil and Korshy[13]). This may explain the abrupt decrease of water absorption values of the fired clay articles with 50% ceramic sludge from 800^o up to 900^{o}C.

The dry & wet compressive strength values of the fired clay articles generally, increase with increasing firing temperature. For the fired articles, the compressive strength values indicate that phases produced upon firing act as binding materials after cooling. Therefore, these values increase against increasing firing temperature. Kom Osheem fired clay articles have the highest dry and wet compressive strength since they have a vitrification temperature of about 910^{o}C, which produces

Table 2. Data of physical and mechanical properties of the fired clay articles with ceramic sludge additives

	Sludge (%)			
	0	15	25	50
Firing Volume Shrinkage (%)				
800^o C	33.50	33.00	32.43	24.88
850^o C	35.18	33.92	33.70	25.29
900^o C	39.84	39.01	37.69	25.80
Water Absorption (%)				
800^o C	14.11	14.56	15.80	17.38
850^o C	10.47	13.41	15.38	16.09
900^o C	10.06	11.60	13.89	15.79
Bulk Density (g/cm^3)				
800^o C	1.741	1.732	1.701	1.650
850^o C	1.775	1.743	1.708	1.697
900^o C	1.936	1.853	1.765	1.699
Dry Compressive Strength (Kg/cm^2)				
800^o C	225	183	164	123
850^o C	235	221	217	199
900^o C	271	237	235	229
Wet Compressive Strength(Kg/cm^2)				
800^o C	171	162	129	93
850^o C	199	184	161	153
900^o C	227	193	186	184

molten phases acting as strong binding material after firing, (Abd El-Ghafour[10]). The compressive strength values of all fired articles are decreased by increasing the percentage of additives at each firing temperature. Mix with 15% ceramic sludge achieved reasonable compressive strength values at all firing temperatures. It's well known that fluxes or impurities and vitrification of clays are dependent upon each other. Feldspars which are included in the clayey raw material and the sludge additives represent the main source of alkalies within the studied mixes. Such alkalies act as a fluxing agent leading to a high degree of vitrification in the clay body. Accordingly, the relative differences in the composition of the studied mixes, their impurities and fluxes may explain the differences in the obtained compressive strength values. Finally, mixes with various percentages of ceramic waste sludge more or less save the workable water, improve the drying sensitivity, in addition to the modification of some physical and mechanical properties of the fired articles into reasonable ones under a normal applied range of firing temperature (800-900°C).

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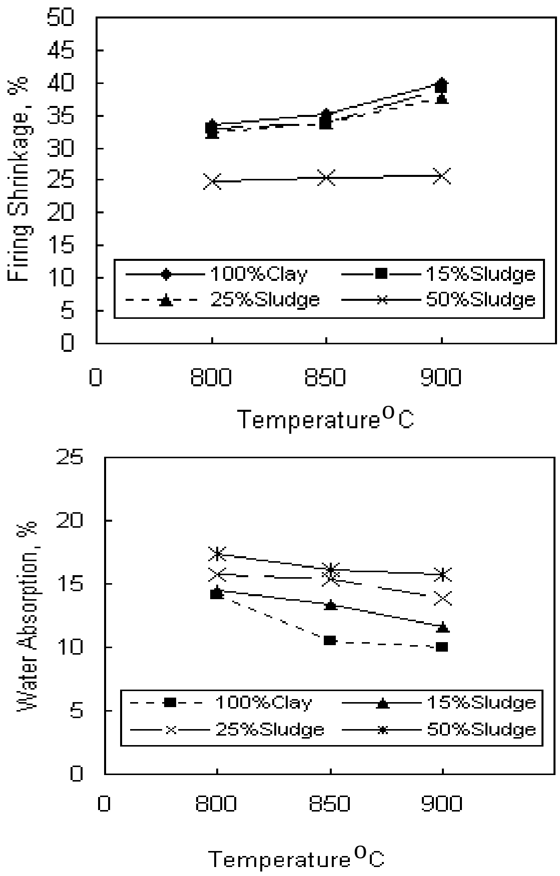

Figure 5. Firing shrinkage and water absorption of the fired clay/ceramic sludge articles.

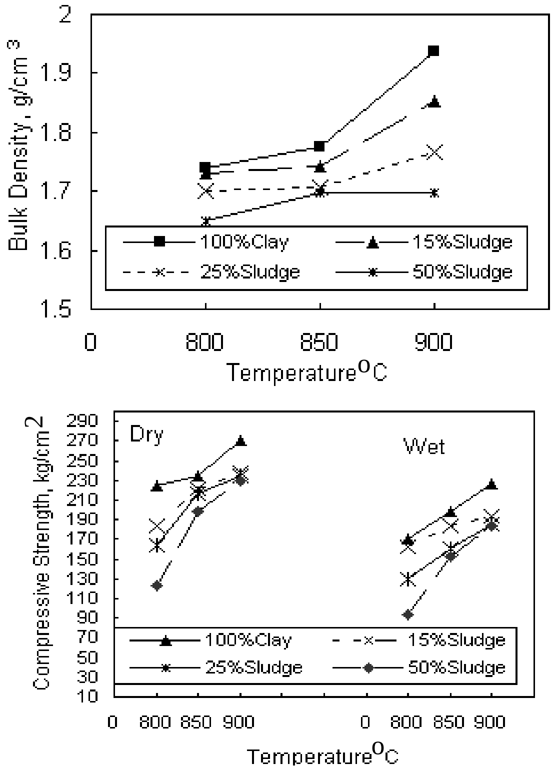

Figure 6. Bulk density and compressive strength of the fired clay/ceramic sludge articles.

The mix with 15% ceramic sludge and 85% clay was applied on an industrial scale in a clay brick fabric. The techniques of mixing , molding , drying and firing were applied according to that followed in the ordinary Egyptian clay bricks fabrics which take the environmental protection in their consideration. Solid green clay bricks with average dimensions of 24.59 length, 12.97 width and 7.94 cm height were extruded and left for drying for two weeks. The green clay bricks were fired in a Hoffman furnace at about 800°C. Table (3) shows the physical and mechanical data of the fired clay/ceramic sludge building bricks. The average dimensions of the fired bricks show that those bricks were suffered from an average firing shrinkage equal to about 15%. The average bulk density value for the fired bricks was 1.74 g/cm^3 , while the average percentage of water absorption was 8.81%. The average percentages of dry and wet compressive strength for the studied fired bricks were 137.73 and 118.12 kg/cm^2, respectively. It should be recorded that, all the results of physical and mechanical properties, except firing shrinkage are completely agree with the limits of the Egyptian Standards[14] and The Egyptian Code for Design and Construction of Buildings[15]. Accordingly, the industrial application of 15% ceramic waste sludge with a highly plastic clays produce suitable building clay bricks by firing at firing temperature as low as 800°C. More over, the huge amounts of ceramic waste sludge can be recycled in the building bricks industry. Finally, a dual target could be achieved; first, an environmental protection against the pollution caused by the accumulation of ceramic waste sludge and second, saving a part of the clayey raw material needed urgently for building brick industry.

Table 3. Data of physical and mechanical properties of the fired clay bricks with 15% ceramic sludge additives.

Sample No.	Dimensions cm.			Dry Weight Kg.	Water Abs. %	Bulk Density g/cm^3	Dry Compr. Strength Kg/cm^2	Wet Compr. Strength Kg/cm^2
	L	W	H					
1	21.0	10.0	7.0	2.591	8.59	1.76	133.57	117.13
2	20.9	10.1	6.9	2.382	9.25	1.64	155.59	109.77
3	21.0	9.9	6.9	2.612	9.09	1.82	144.73	122.66
4	21.0	10.0	7.0	2.542	9.33	1.73	123.86	114.69
5	21.0	10.1	7.0	2.474	9.02	1.67	126.48	117.13
6	21.0	10.0	6.8	2.403	8.79	1.68	138.43	116.38
7	21.0	10.1	6.9	2.719	8.59	1.86	140.91	121.67
8	20.9	10.0	6.5	2.412	8.43	1.78	129.33	124.72
9	20.9	10.0	7.0	2.471	8.55	1.69	143.48	118.40
10	21.0	10.1	6.8	2.561	8.42	1.78	140.91	118.66
Average	20.9	10.0	6.9	2.516	8.81	1.74	137.73	118.12

4. CONCLUSIONS

The studied clays are silty to silty mud with clay> silt> sand fractions. The identified clay mineral assemblage includes montmorillonite, montmorillonite-illite, kaolinite and illite in a descending order of abundance. They contain quartz, feldspars and calcite in addition to low Al_2O_3 and high SiO_2 contents. The mineralogical composition of the ceramic sludge mainly includes quartz and albite in addition to kaolinite and illite. Its chemical composition reveals the enrichment of SiO2, CaO and Na_2O. The percentage of Al_2O_3 in the sludge is nearly similar to that in the studied clays. It's concluded that:

(1) Addition of ceramic sludge to a clayey material decreases its plasticity coefficient, but not affects greatly the plastic behaviour of the studied mixes.
(2) Addition of ceramic sludge to the studied sensitive clay decreases its drying sensitivity coefficient (D.S.C.) from very sensitive to insensitive during the drying process.
(3) The more addition of ceramic sludge the less firing shrinkage and bulk density values in addition to the more water absorption values will be obtained.
(4) The compressive strength values of the fired clay articles generally, increase with increasing the firing temperature.

(5) The mix with 15% ceramic sludge achieved reasonable compressive strength values at all firing temperatures. So, it was chosen for industrial application.
(6) All physical and mechanical properties of the fired clay building bricks, except firing shrinkage are completely agree with the limits of The Egyptian Standards No.1756,(1989) and The Egyptian Code for Design and Construction of Buildings.
(7) Ceramic waste sludge can be used in clay brick making with a suitable percentage (not more than 15%), and firing at $800^{o}C$.
(8) Utilization of ceramic waste sludge in building clay bricks industry shares in the environmental protection against the pollution caused by the accumulation such solid waste, in addition to saving the great need of clayey raw material for making clay building bricks.
(9) Recycling of ceramic waste sludge in clay building bricks industry can produce green building units have a zero waste energy in addition to minimize the energy consumption and the cost of building.

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